REMARKS

Entry of the foregoing, reexamination and reconsideration of the subject application are respectfully requested in light of the amendments above and the comments which follow.

As correctly noted in the Office Action Summary, claims 1-12 were pending. By the present response, claims 13-21 have been added, claims 1-12 amended. Thus, upon entry of the present response, claims 1-21 remain pending and await further consideration on the merits.

Support for the present claim amendments can be found, for example, in at least the following portions of the disclosure: the original claims.

ALLOWABLE SUBJECT MATTER

Applicants gratefully acknowledge the indication at paragraph 7 of the Official Action that claims 4, 6, 7, and 12 would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims. By the present amendments, each of original claims 4, 6, 7 and 12 have been rewritten in independent and presented as claim 4; claims 6 and 15; claims 7, 16 and 17; and claims 12 and 13, respectively.

CLAIM OBJECTIONS

In the Official Action, at paragraph 1, claims 1, 3, 7 and 11 were objected to for the noted informalities. Applicants have amended claims 1, 3, 7 and 11 to clarify the claims and address the noted informalities. Reconsideration and withdrawal of the objections are requested.

REJECTION UNDER 35 U.S.C. § 112, SECOND PARAGRAPH

In the Official Action, at paragraph 2, claim 8 was rejected under 35 U.S.C. § 112, second paragraph, as allegedly being indefinite. Applicants have amended claim 8 to clarify that one fiber Bragg grating each is held between a first pressure member and a supporting member and a second pressure member and a second supporting member. Reconsideration and withdrawal of the objections are requested.

CLAIM REJECTIONS UNDER 35 U.S.C. §102 and UNDER 35 U.S.C. §103

Claims 1-3, 5 and 9-11 stand rejected under 35 U.S.C. § 102(e) as being anticipated by U.S. Patent No. 6,490,931 B1 issued to Fernald et al. (hereafter "*Fernald et al.*") for the grounds set forth beginning at paragraph 3 of the Official Action.

Claim 8 stands rejected under 35 U.S.C. § 103(a) as being unpatentable over *Fernald et al.* for the grounds set forth beginning at paragraph 6 of the Official Action.

Both of these claim rejections are traversed because the *Fernald et al.* reference relied upon as the basis for the rejection does not qualify as prior art against the present claims under the indicated statutory standard.

Applicants have provided evidence in the attached Declaration pursuant to 37 C.F.R. § 1.131 that Applicants reduced the claimed invention to practice and/or conceived the claimed invention and were diligent from a date prior to the critical date of the *Fernald et al.* reference, e.g., prior to December 4, 1998. Thus, the disclosure in the *Fernald et al.* reference was not described in a patent granted on an application for patent by another filed in the United States before the invention by the Applicants as required by 35 U.S.C. § 102(e).

From the above, Applicants respectfully assert that the grounds for rejection of Applicants' claims is erroneous because the *Fernald et al.* reference is not prior art under 35 U.S.C. § 102(e) against the claims of the present application. Withdrawal of the rejection is respectfully requested.

CONCLUSION

From the foregoing, further and favorable action in the form of a Notice of Allowance is earnestly solicited. Should the Examiner feel that any issues remain, it is requested that the undersigned be contacted so that any such issues may be adequately addressed.

Respectfully submitted,

BURNS, DOANE, SWECKER & MATHIS, L.L.P.

Date: August 28, 2003

By: Jeffrey G. Killian

Jeffrey G. Killian
Registration No. 50,891

P.O. Box 1404
Alexandria, Virginia 22313-1404
(703) 836-6620

Exhibit 1

Fiber Bragg Grating Sensor for Differential Pr ssur Measurements

K. Bohnert and H. Brändle

ABB Corporate Research, CHCRCE.3

CH 5405 Baden-Daettwil, Switzerland

I. BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a method and to devices for measuring differential pressures and temperatures of fluids. In combination with a Venturi nozzle the devices can be utilized to determine fluid flow rates. A particular field of application are oil and gas production wells. Here, flow rate measurements at various locations along an oil production tube allows for example to determine the oil inflow from different production zones. As a result improved reservoir management is possible.

2. Prior Art

The efficient control and operation of oil production wells requires continuous monitoring of downhole parameters including pressure, temperatures, and flow rates at distributed locations within the well. Optical sensors for monitoring pressure and temperature in harsh environments such as oil production wells have been described in our previous inventions "Optical Fiber Pressure Sensor" by K. Bohnert, H. Brändle, and P. Bodor (V-Nr. 97332, Ref. 1) and "Fiber Laser Pressure Sensor" by K. Bohnert and H. Brändle (V-Nr. 97356, Ref. 2). Further references on prior art are given therein. In addition, various differential pressure sensors have been disclosed. Examples include a sensor based on the deformation of a pair of spaced diaphragms exposed to pressure [3], a sensor with a semiconductor chip that has two pressure-sensitive surfaces[4], a sensor with two piezoelectric networks and two internal reference pressures[5], and a micro-machined flow sensor device using a pressure difference[6].

II. OBJECTIVES OF THE INVENTION

The objective of the invention is a fiber-optic sensor for the measurement of differential pressures of liquids and gases with good resolution and large dynamic range. The sensor may be utilized in combination with a Venturi nozzle to measure fluid flow rates. The objectives include that the differential pressure is measured by a single sensor as opposed to taking the difference of absolute pressure readings by two independent sensors. The differential pressures to be measured are roughly in the range between 0.1 kPa (0.001bar) and 10 MPa

(100 bar). The absolute pressures may be in excess of 100 MPa (1000 bar). The environmental temperatures are in the range 0 to 230 deg C. The sensors must be able to withstand the corrosive environment of oil production wells. Other objectives are a small sensor diameter (20 -30 mm or less) and the capability to multiplex a series of sensors. Furthermore, the sensor signal should contain information not only on the differential pressure but also on the environmental temperature.

III. SUMMARY OF THE INVENTION

The fiber Bragg grating pressure sensor which we described in Ref. 1 is modified such that the output signal corresponds to the difference of two absolute pressures. A steel tube separates two fluid-filled compartments with pressures p_1 and p_2, respectively. The difference in fluid pressure between the two compartments represents the differential pressure to be measured. A change in differential pressure produces an longitudinal expansion or compression of the steel tube. The resulting displacement of the tube end is transferred to a fiber Bragg grating. The associated change in fiber strain results in a shift of the Bragg wavelength. The Bragg wavelength is an absolute measure for the differential pressure. By a combination of steels with different thermal expansion coefficients the sensor is inherently temperature-compensated. Different arrangements of pressure compartments are considered.

IV. DESCRIPTION OF THE INVENTION

Transducer Configuration

A first preferred embodiment of the invention is shown in Figure 1. Here, a longitudinal section of a differential pressure transducer is displayed. The Figure is not to scale and is meant only as a schematic presentation of the transducer configuration. The transducer has two concentric preferably cylindrical inner tubes (transducer tube, support tube) which are encapsulated by an again preferably cylindrical outer tube (housing tube). The housing tube ends are closed by end plates. The transducer and support tubes are welded at one end to one of the end plates of the housing tube as shown in Figure 1. The opposite end of the transducer tube is closed by another end plate whereas the support tube is open. The interior of the transducer tube is filled by a fluid which is exposed to pressure p_1. The volume between the transducer and housing tubes is filled by a fluid exposed to pressure p_2. A change in differential pressure, $p_1 - p_2$, shortens or elongates the transducer tube, depending on the sign of the pressure change. This length change is transmitted to a fiber Bragg grating (FBG 1) which is suspended between two mounts connected to the ends of the transducer and support tubes, respectively. The resulting change in grating strain causes a shift in Bragg wavelength which is proportional to the change in differential pressure.

The longitudinal stress, σ_x, the radial stress, $\sigma_r(r)$, and the tangential stress, $\sigma_\varphi(r)$, of the transducer tube under internal and external pressures, p_1 and p_2, are given by[7]

$$\sigma_x = (p_1R_1^2 - p_2R_2^2) / (R_2^2 - R_1^2) \qquad (1)$$

$$\sigma_r(r) = -[p_2R_2^2 - p_1R_1^2 + (p_1 - p_2) R_1^2 R_2^2/r^2] / (R_2^2 - R_1^2) \qquad (2)$$

$$\sigma_\varphi(r) = -[p_2R_2^2 - p_1R_1^2 - (p_1 - p_2) R_1^2 R_2^2/r^2] / (R_2^2 - R_1^2) \qquad (3)$$

Here, R_1 and R_2 are the inner and outer radii of the tube, respectively. The equations are valid in middle part of the tube, i.e. further than $2R_2$ away from the tube ends.

The longitudinal strain, ε_t, of the transducer tube is given by

$$\varepsilon_t = (1/E) [\sigma_x - \mu(\sigma_\varphi + \sigma_r)] \qquad (4)$$

$$\varepsilon_t = (1/E) [(p_1R_1^2 - p_2R_2^2) / (R_2^2 - R_1^2)] [1 - 2\mu] \qquad (5)$$

where E is Young's modulus, and μ is the Poisson number.

The change, ΔL_T, in tube length, L, is

$$\Delta L_t = \varepsilon_\tau L \qquad (6)$$

The longitudinal, radial, and tangential stresses of the open-ended support tube are according to equ. (1) - (3) with $p_1 = p_2$

$$\sigma_x = \sigma_\varphi = \sigma_r = -p_2 \qquad (7)$$

i.e. the stresses are independent of the tube radii. (The negative sign denotes compressive stress).

The longitudinal support tube strain, ε_s, is

$$\varepsilon_s = (1/E) (\sigma_x - \mu\sigma_\varphi - \mu\sigma_\rho) \qquad (8)$$

$$\varepsilon_s = (-p_2/E) (1 - 2\mu) \qquad (9)$$

The change, ΔL_S, in support tube length, L, is

$$\Delta L_s = \varepsilon_s L \qquad (10)$$

The change in length of the fiber section with the Bragg grating is thus

$$\Delta L_G = \Delta L_t - \Delta L_s \qquad (11)$$

$$\Delta L_G = L (1/E) [1 - 2\mu] [(p_1R_1^2 - p_2R_2^2) / (R_2^2 - R_1^2) + p_2] \qquad (12)$$

Here, it is assumed that the two tubes have equal length L and consist of the same material, i. e. have the same Young's modulus E, and Poisson number μ. With $\Delta P = p_1 - p_2$ equ. (13) can be rewritten as

$$\Delta L_G = L (1/E) [1 - 2\mu] [\Delta p R_1^2 / (R_2^2 - R_1^2)] \qquad (13)$$

It is obvious that the change in grating length depends only on the pressure difference, Δp, but not on the absolute values of p_1 and p_2.

The change in strain of the fiber grating is

$$\Delta\varepsilon_G = \Delta L_G / l \qquad (14)$$

where l is the length of the suspended fiber section containing the grating.

The shift in Bragg wavelength is for a wavelength of 1550 nm[8]

$$\Delta\lambda = 1.21 \cdot 10^6 \,\text{pm}\, \Delta\varepsilon_G \qquad (15)$$

The transducer and support tubes must have equal lengths (measured as indicated in Figure 1) in order to arrive at the relationship given by equ. (13). The transducer tube which protrudes out of the support tube by a distance l (length of the suspended fiber grating section) is therefore mounted on a base with height l.

FBG 1 must be mounted with sufficient tensile strain such that at all conditions of operation the strain is non-vanishing. The fiber feed-throughs in the end plate of the housing tube must be pressure-tight.

With an appropriately large ratio L/l of tube length and fiber grating length l a relatively large strain of the fiber Bragg grating and thus a good resolution of differential pressure can be achieved at relatively low strains of the transducer and support tubes. The pressure-induced strains of the tubes which preferably consist of steel should be kept less than 0.001 in order to avoid inelastic behavior and hysteresis effects. For the fiber Bragg grating, on the other hand, the strain vs stress relationship is linear and free of hysteresis up to strains well above 0.01. The same is true for the Bragg wavelength shift as a function of fiber strain.

In principle, the differential pressure could be measured by simply exposing FBG 1 to pressure p_1 and FBG 2 to pressure p_2 and measuring the difference in pressure-induced Bragg wavelength shift. However, due to the small sensitivity of the Bragg wavelength to hydrostatic pressure[9] the resolution of differential pressure would be limited. It is one of the objectives of this invention to significantly increase the pressure resolution by means of the transducers described here.

With, for example, $E = 196 \cdot 10^9$ N/m^2 and $\mu = 0.28$ (steel), L =150 mm, l = 10 mm, transducer tube radii R_1 = 5 mm, R_2 = 4.8 mm the shift in Bragg wavelength per change in differential pressure is

$$\Delta\lambda / \Delta p = 479 \text{ pm/MPa} \quad (47.9 \text{ pm/bar}) \qquad (16)$$

With commercially available fiber Bragg grating interrogation systems based on tunable Fabry Perot filters a wavelength resolution of about 1 pm can be achieved. The corresponding resolution in differential pressure is thus 2.1 kPa (21 mbar). The onset of inelastic creeping determines the maximum differential pressure which can be applied to the sensor. With the given parameters the transducer tube deformation remains within its elastic limits for differential pressures up to about 5 MPa (50 bar). The resulting Bragg wavelength shift is 2.4 nm.

The radial dimensions of the support tube are less critical as this tube is not exposed to any differential pressure. In a practical case the inner and outer tube radii could be 6 mm and 8 mm, respectively, and the inner and outer radii of the outer housing could be 15 mm and 21 mm, respectively. The outer housing could then withstand pressures, p_2, in excess of 100 MPa (1000 bar).

The Bragg wavelength of FBG 1 is not only affected by a change in differential pressure but also by the following effects:

- Change in the pressure p_2 directly acting on the grating: The resulting wavelength shift is a few hundred pm for a pressure change of 100 MPa (1000 bar).
- Thermal shift of Bragg wavelength: The Bragg wavelength shifts by 10.3 pm/ deg C at 1550 nm (at constant grating strain)[8].
- Differential thermal expansion of transducer and support tubes: The grating strain resulting from the differential thermal expansion of the two tubes gives a further shift in Bragg wavelength (see below).

These effects must be compensated in order to achieve an unambiguous differential pressure measurement. The compensation is done by means of a further Bragg grating (FBG 2) which is suspended over a length l at the base of the support tube. The grating is subjected to the same pressure, temperature, and thermal strain changes as FBG 1. The Bragg wavelengths of the two gratings are similar, but sufficiently different so that no overlap occurs at all conditions of operation. By taking the difference of the Bragg wavelengths the above mentioned perturbations cancel. Only changes in differential pressure, Δp, cause a shift in wavelength difference.

Furthermore, there is a third grating (FBG 3) which is mounted free of any strain in one of the end plates of the housing. This grating serves for an independent measurement of the environmental temperature. The temperature information also can be used to eliminate any residual temperature effects, if there are any, which are not removed by the procedure as just described.

Inherent Temperature Compensation

In order to inherently compensate the thermal shift of the Bragg wavelength of FBG 1 the transducer tube and the support tube are composed of materials with different thermal expansion coefficients, α_1 and α_2, respectively. The two coefficients are chosen such that the differential thermal expansion of the tubes results in a change of the grating strain, $\Delta\varepsilon_T$, which just compensates the thermal Bragg wavelength shift (see also Ref. 10). The thermal fractional Bragg wavelength shift at constant grating strain is

$$(\Delta\lambda/\lambda)_T = (\delta\lambda/\lambda) / \delta T)\ \Delta T = (6.67\text{x}10^{-6} / \text{deg C})\ \Delta T. \qquad (17)$$

The fractional wavelength shift due the change in fiber strain, $\Delta\varepsilon_T$ which results from the differential thermal expansion is

$$(\Delta\lambda/\lambda)_{\varepsilon(T)} = (\delta\lambda/\lambda) / \delta\varepsilon)\ \Delta\varepsilon_T = 0.78\ \Delta\varepsilon_T \qquad (18)$$

where $\Delta\varepsilon_T$ is given by

$$\Delta\varepsilon_T = [\ ((\alpha_1(L+l) - \alpha_2 L) - \alpha_f\, l\,) / l\ ]\ \Delta T \qquad (19)$$

Here, $a_f = 0.5x10^{-6}$ / deg C is the thermal expansion coefficient of the fiber, and it is assumed that the base of the transducer tube with height l has the same thermal expansion, α_1, as the transducer tube.

The condition $(\Delta\lambda/\lambda)_{e(T)} = - (\Delta\lambda/\lambda)_T$ yields with the given numbers for the temperature and strain response of the grating

$$(\alpha_2 L - \alpha_1(L+l)) / l = 8.0 \cdot 10^{-6} / \text{deg C} \qquad (20)$$

Assuming L = 150 mm, l = 10 mm, and $\alpha_1 = 12.4 \cdot 10^{-6}$ / deg C, the thermal expansion coefficient of the support tube must be $\alpha_2 = 14.0 \cdot 10^{-6}$ / deg C in order to compensate the temperature-induced Bragg wavelength shift. Since for increasing temperature $\Delta\varepsilon_T$ must be negative, i. e. the fiber strain must be decreased in order compensate the temperature-induced Bragg wavelength shift, the grating must be anchored with an initial pre-tension which is large enough that at the lowest temperature of operation the fiber is still under tension.

Preferably, the transducer and support tubes are made of corrosion-resistant steel. This limits the number of available combinations of different thermal expansion coefficients, and complete temperature compensation for a given set of parameters L and l may not be possible with the mechanical design as given in Fig. 1. However, one or both of the tubes can be composed of two or more segments with adjustable length and different thermal expansion coefficients in order to tailor the differential thermal expansion of the two tubes. A example is shown in Fig. 2. Here, the support tube consists of two segments with lengths L' and L", respectively, with L' + L" = L. The transducer tube consists, as before, of a single segment only. The support tube segment with length L" is made from the same steel type as the transducer tube and has the same thermal expansion coefficient, a_1. The support tube segment with length L' has a thermal expansion coefficient a_2. The proper length, L', follows from eq. (20) if L in eq. (20) is replaced by L':

$$[a_2 L' - a_1 (L'+l)] / l = 8.0x10^{-6} / \text{deg C} \qquad (21)$$

The length, L", is then given by L" = L - L'. The two different steel types should have essentially equal Young's moduli and Poisson numbers, of course, in order not to impair the differential pressure measurement.

There are two steel alloys available which are sufficiently corrosion-resistant and which have thermal expansion coefficients of 12.4×10^{-6} and 17.0×10^{-6} that are sufficiently constant in the temperature range of interest (0-230 deg C). Assuming again L = L' + L" = 150 mm and l = 10 mm the following values for L' and L" result: L' = 44.3 mm and L" = 105.7 mm.

As in Figure 1 there are again two further Bragg gratings FBG 2 and FBG 3. FBG 3 again serves to monitor the environmental temperature. FBG 2 is as FBG 3 free of strain and sees the environmental temperature and pressure p_2. The effects of pressure p_2 on FBG 1 are compensated by subtracting from the Bragg wavelength of FBG 1 the difference of the Bragg wavelengths of FBG 2 and FBG 3. An advantage of the configuration in Figure 2 is that only one grating (FBG 1) must be mechanically anchored under tensile strain. A further advantage of inherent temperature compensation is that the overall tuning range of a compensated grating is smaller (no temperature contribution to the Bragg wavelength shift) so that a larger number of gratings can be interrogated using a common broad band source (see grating interrogation below).

Further Transducer Configurations

Another modification of the transducer of Figure 1 is shown in Figure 3. Here, at varying differential pressure, $\Delta p = p_1 - p_2$, the strain of grating FBG 1 varies as described above. FBG 2 sees the same change in strain, however with opposite sign. By taking the difference of the two Bragg wavelengths the differential pressure induced Bragg wavelength shift doubles. Furthermore, Bragg wavelength changes associated with changes in pressure p_2 and thermal effects (temperature sensitivity of gratings and differential thermal expansions of transducer and support tubes) cancel. FBG 3 serves again for temperature monitoring.

Similar as in Figure 2 the support tube may be composed of segments with different thermal expansion coefficients in order to inherently reduce or cancel temperature-induced shifts of the Bragg wavelengths of FBG 1 and 2.

Figure 4 shows a configuration with two transducer tubes in series. At varying pressure difference, $p_1 - p_2$, one tube is elongated and the other one is compressed. The common end plate of the transducer tubes is thus displaced in proportion to $p_1 - p_2$. Here, it is assumed that the wall thickness of the outer housing tube is sufficiently large so that the pressure induced strain of the housing is negligible. The displacement of the common end plate of the transducer tubes is again transmitted to a fiber Bragg grating (FBG 1) which is mounted between this end plate and a support tube concentric with one of the transducer tubes. As in Figure 2 the support tube may be composed of segments with different thermal expansion coefficients to cancel temperature-induced shifts of the Bragg wavelengths of FBG 1. FBG 2 is unstrained and serves for temperature measurement.

In this configuration the fiber with the two gratings is not exposed to any fluid pressure. The volume outside the transducer tubes is preferably under vacuum or filled with a low pressure gas such as nitrogen. In contrast to the previous configurations there is therefore no need to

take into account Bragg wavelength shifts caused by exposure of the gratings to fluid pressure. The transducer tubes must be designed such that they can withstand the full pressures p_1 and p_2 whereas in the previous configurations they had to withstand only the maximum differential pressure. The maximum achievable resolution in differential pressure is therefore less. For maximum pressures, p_1 and p_2, of 100 MPa (1000 bar) and a Bragg wavelength resolution of 1 pm the resolution in differential pressure is expected to be on the order of 1 bar for adequately designed transducer tubes of steel. On the other hand differential pressures up to p_1 and p_2 can be measured.

With the configuration of Fig. 5 the displacement of the common end plate of the transducer tubes is again transmitted to two fiber gratings (FBG 1 and FBG 2). The temperature is measured with a third, strain-free grating (FBG 3). The transducer of Fig. 6 combines two transducers of the type as described in Ref. 1 in a common housing. The two pressures are measured separately, and the differential pressure is determined from the wavelength shifts of FBG 1 and FBG 2. The transducer of Fig. 7 has two transducer tubes which are arranged in parallel. The fiber grating is suspended between the end plate of the first tube and a support structure mounted to the end plate of the second tube. The support structure could be composed of different steel types and designed such that net thermal changes in dimension compensate the temperature dependence of the grating. Finally, the transducer of Figure 8 is equivalent to the one of Figure 1 but has non-concentrical transducer and support tubes.

Compressive Grating Strain

The fiber gratings which measure the pressure-induced transducer tube elongation are under tensile strain, and variations in differential pressure cause a variation in the tensile fiber strain. In principle, the gratings could be also mounted, by means of an appropriate fixture, under compressive strain, and the amount of compressive strain could be varied by pressure variations[11].

Fiber Grating Anchoring

Various methods to mechanically anchor the fiber gratings have been described in Ref. 1. A further method is to solder the fused-silica fiber to a fused-silica substrate using glass solder with a matched thermal expansion coefficient (Figure 9). This type of anchoring is commercially available.

Fiber Grating Interrogation

An advantage of fiber Bragg grating sensors is that several gratings distributed along a single fiber or along several fibers can be easily multiplexed. One possibility among others to interrogate one or several gratings is to use a broad-band light source and a narrow-band tunable spectral filter like a tunable Fabry Perot filter[12] or tunable acousto-optic modulator[13] (Fig. 10). Preferred sources include broad-band rare earth doped fiber sources, luminescent diodes (LEDs), and superluminescent diodes (SLDs). The spectral emission of the source

covers the tuning ranges of the gratings to be interrogated. The tuning ranges of the individual gratings must not overlap in order to unambiguously distinguish the gratings. As the filter is tuned over the spectral range in question the photo-detector registers a signal as the filter passes the Bragg wavelength of a grating. The interrogation system has one or several temperature-stabilized reference Bragg gratings or other means which provide reference wavelengths for wavelength calibration. Typically, the bandwidth of the gratings is 0.2 nm, the peak reflectivity is above 0.9, and the grating length is about 10 mm.

Pressure sensing in oil wells may require large distances (several km) between the transducers and the source/ detection side of the sensor. Therefore, it is advantageous to operate the gratings in the spectral range around 1550 nm where optical losses in the fiber are lowest. Here, the usable spectral width of the available broad-band sources is on the order of 50 nm.

The temperature-sensing gratings have tuning ranges of 2.4 nm for a temperature span of 230 deg C. Assuming a maximum strain variation of 0.003 for the differential pressure-sensing gratings the associated Bragg wavelength shift is 3.6 nm. (There is an additional temperature-induced Bragg wavelength shift of up to 2.4 nm without inherent temperature compensation). A temperature-compensated transducer as shown in Figure 2 then requires a total spectral window of roughly 7 nm (including some margins between the tuning ranges of the individual gratings). Consequently, up to 7 transducers can be unambiguously interrogated with a light source which has a usable spectral width of 50 nm. The number of multiplexed transducers can be further increased by adding for example time-division multiplexing[14] and/ or optical fiber switches[15] which allow to address several fibers each one with a series of imbedded gratings.

In Figure 10 the transducer a multiplexed in series. A parallel arrangement or a combination of parallel and serial arrangements is possible as well.

Measurement of Flow Rates

The differential pressure sensor can be used in combination with a Venturi nozzle to determine fluid flow rates. The flow velocity, v, is given by

$$v = \{ 2(p_2 - p_1) / (\rho (A_2^2 / A_1^2 - 1)) \}^{½} \qquad (10)$$

where A_1 and A_2 are the tube cross section as defined in Fig. 11 and r is the fluid density.

V. REFERENCES

[1] K. Bohnert, H. Brändle, and P. Bodor (V-Nr. 97332)
[2] K. Bohnert, H. Brändle (V-Nr. 97356)
[3] US patent 5 386 729, issued Feb. 7 1995, inventors: S. E. Reed et al.
[4] US patent 5 412 992, issued May 9 1995, inventors: T. Tobita et al.
[5] US patent 5 437 189, issued Aug. 1 1995, inventors: C. H. Brown et al.
[6] US patent 5 515 735, issued May 14 7 1996, inventors: V. Sarihan
[7] Hütte, Grundlagen der Ingenieurwissenschaften, H. Czichos, Ed., Spinger-Verlag 1991

[8] K. O. Hill and G. Meltz, J. Lightwave Technology 15, 1263-1276, 1997.
A. D. Kersey et al., J. Lightwave Technology 15, 1442-1463, 1997.
[9] M. G. Xu et al., Electron. Lett. 29(4), 398-399, 1993.
[10] U.S. patent 5 042 898, issued: 08/1991, inventor: W. W. Morey et al.
[11] U.S. patent 5 469 520, issued: 11/1995, inventor: W. W. Morey et al.
[12] M. A. Davis et al., Proc SPIE 1994 2nd European Conference on Smart Structure Materials, Glasgow 1994, vol 2361, pp 342-345.
[13] M. G. Xu et al., J. Lightwave Technology, 14, 391-396.
[14] T. A. Berkoff et al., Proc SPIE 1994 2nd European Conference on Smart Structure Materials, Glasgow 1994, vol 2361, pp 350-353.
[15] M. A. Davis et al., Electron. Lett. 32, 1393, 1996.

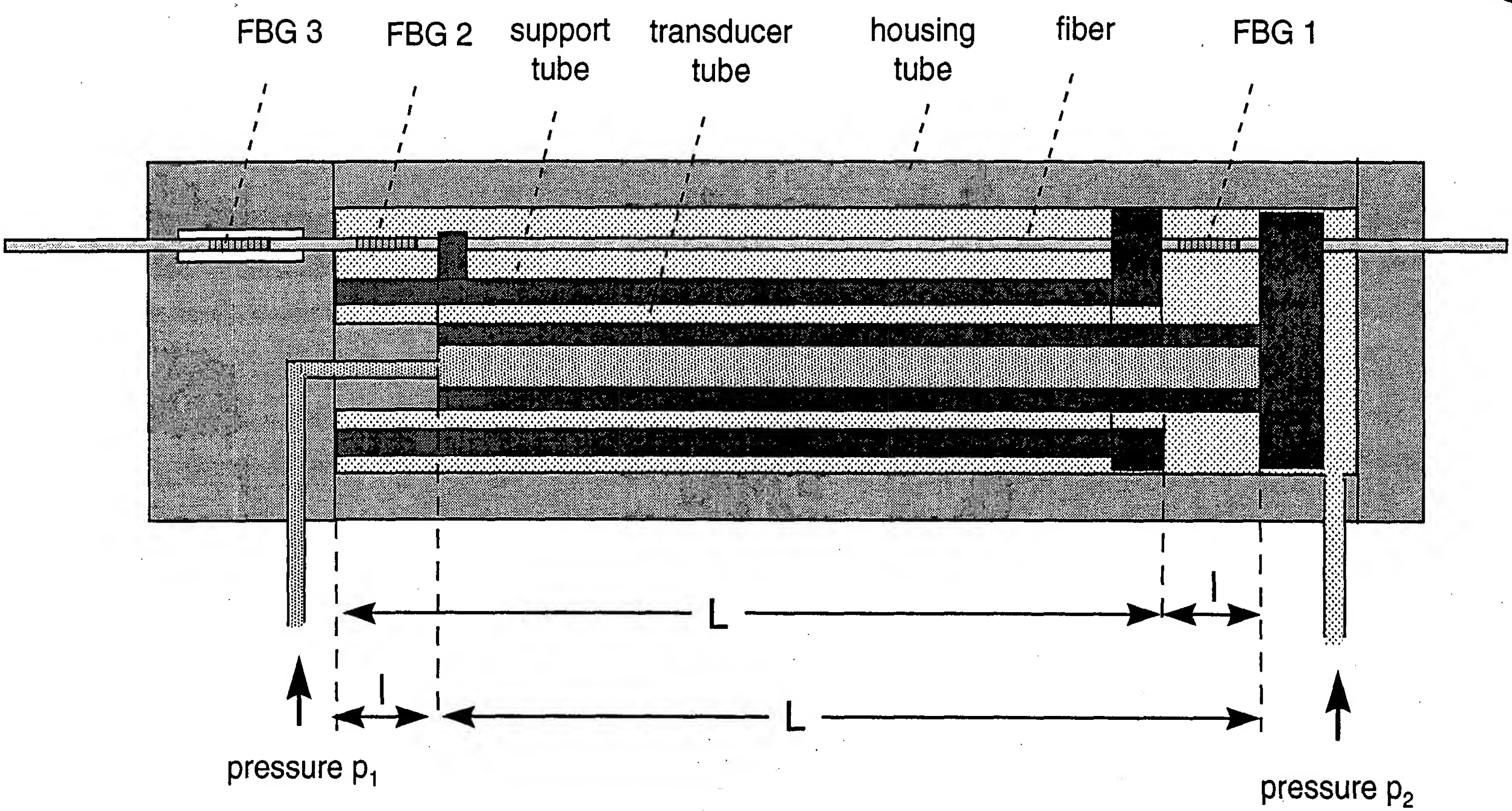
FBG 3
FBG 2
support tube
transducer tube
housing tube
fiber
FBG 1
L
l
l
L
pressure p_1
pressure p_2

Figure 1

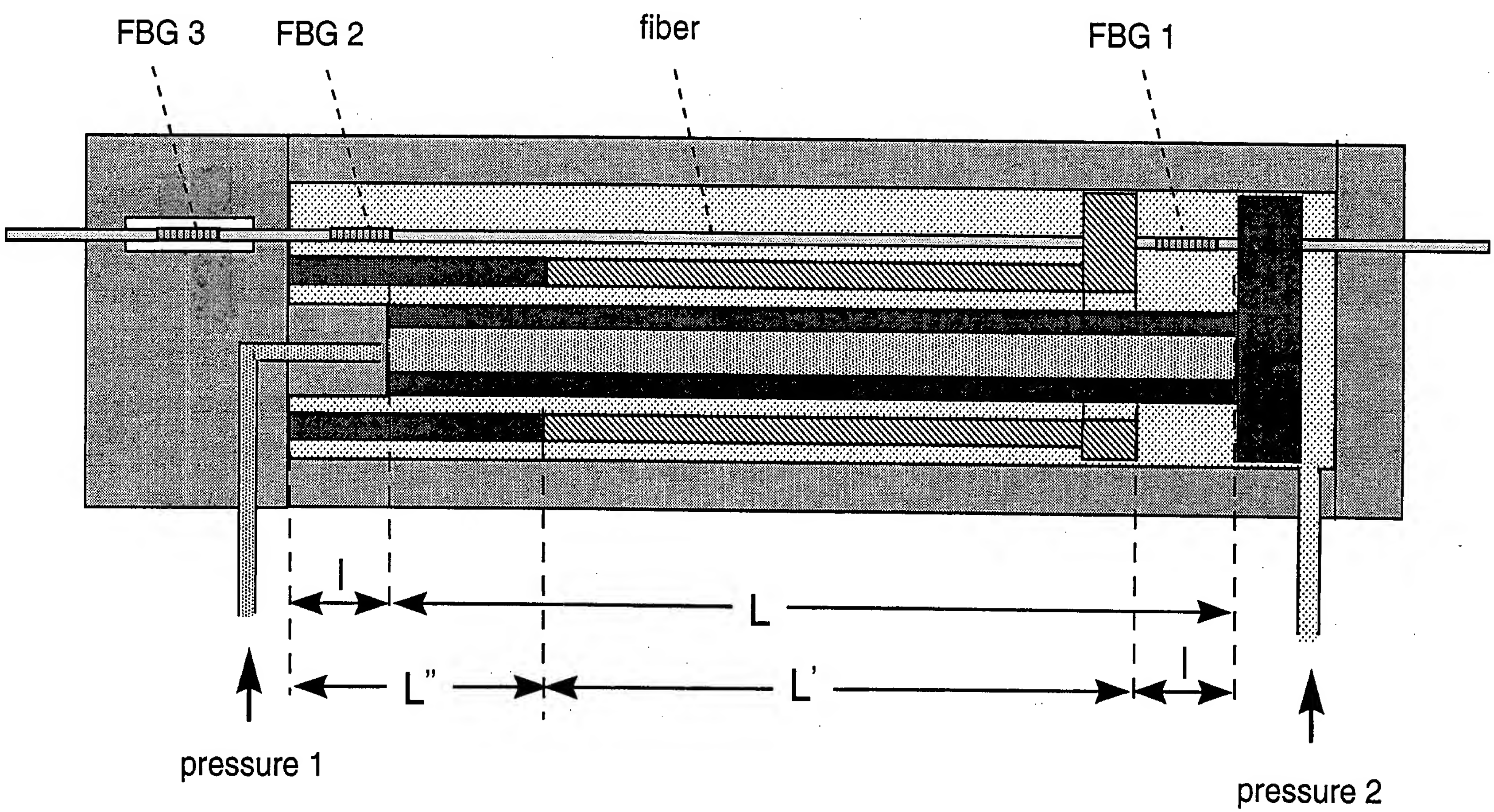

Figure 2

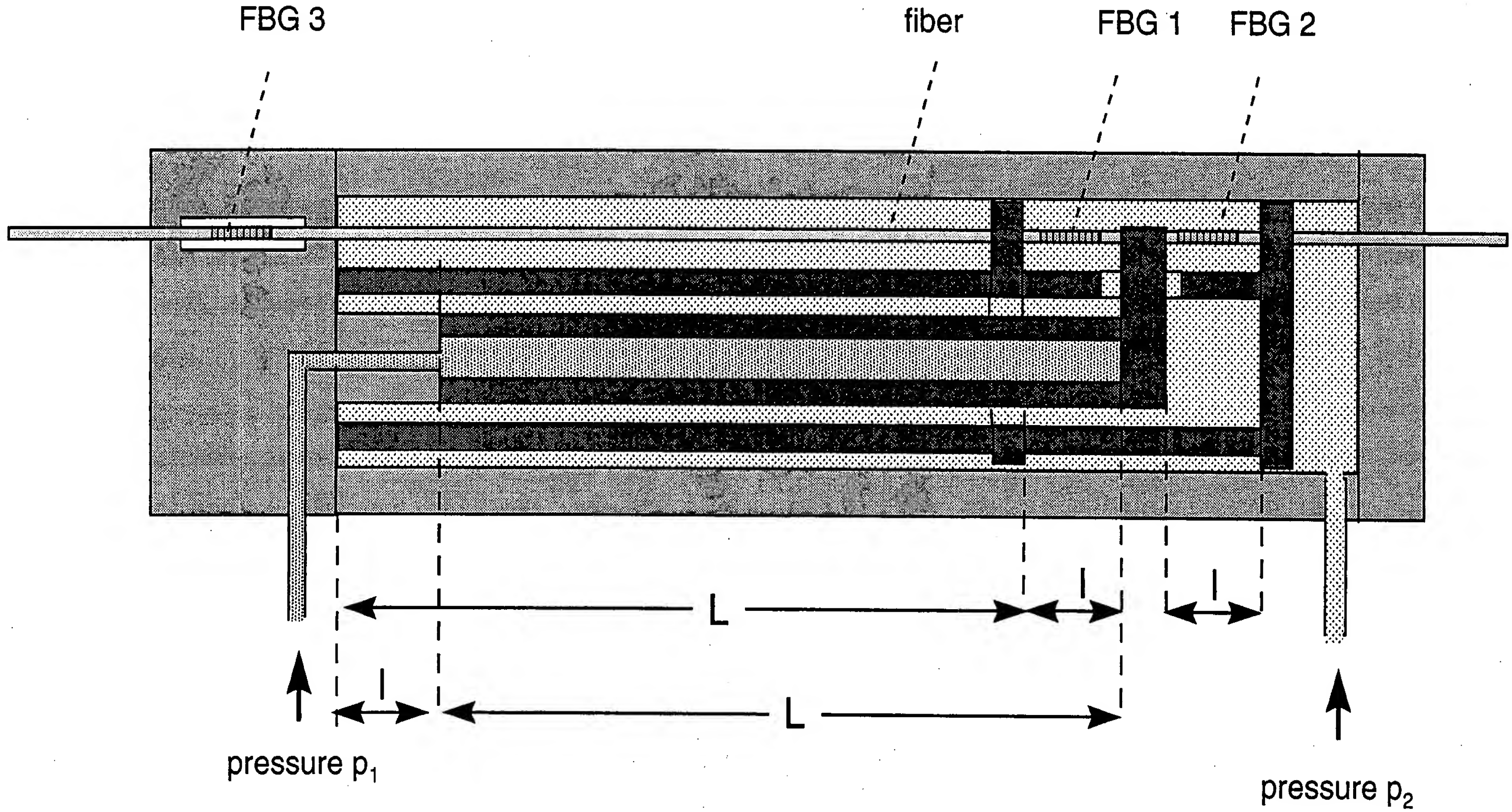

Figure 3

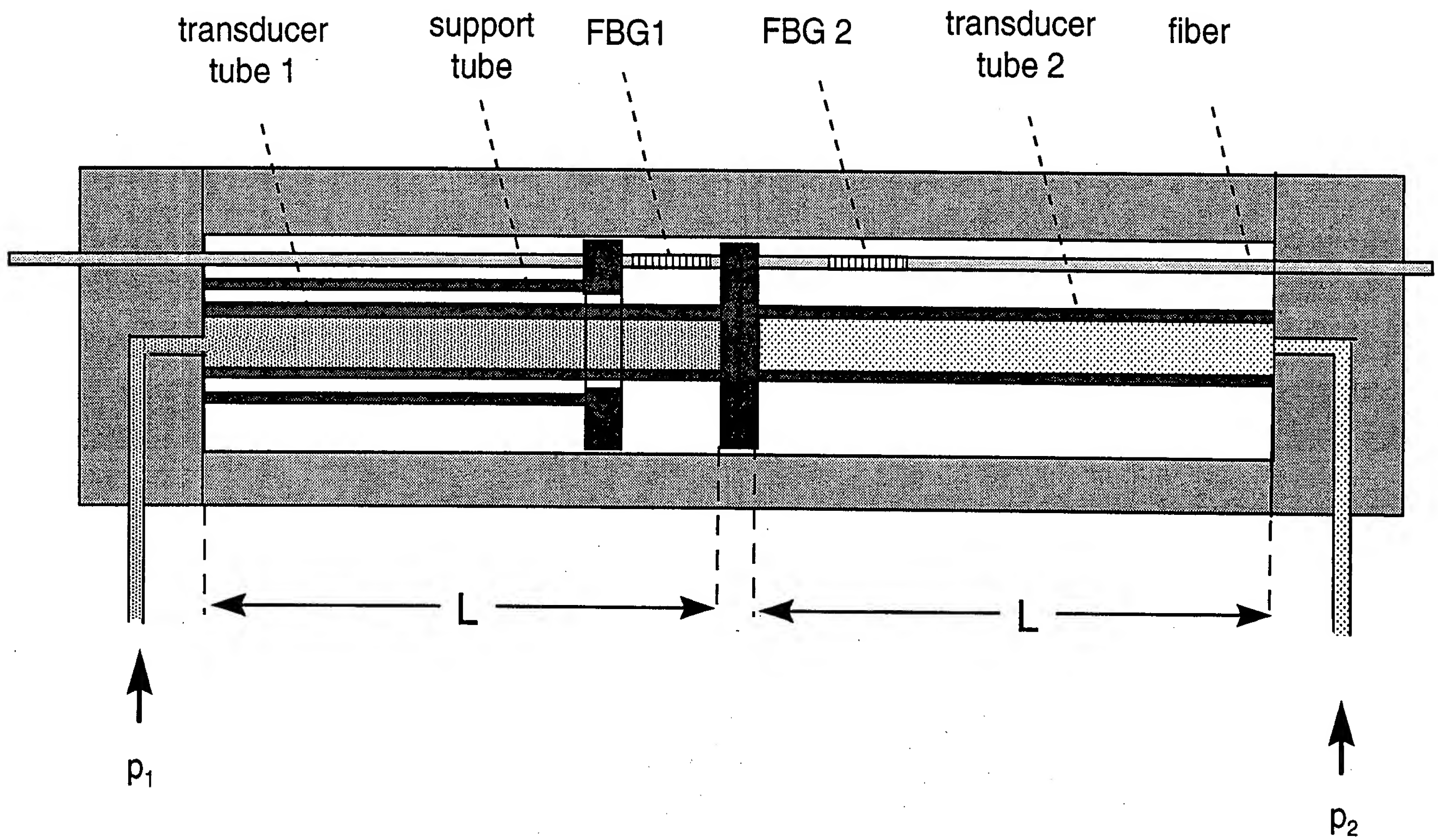
transducer tube 1
support tube
FBG1
FBG 2
transducer tube 2
fiber
L
L
p1
p2

Figure 4

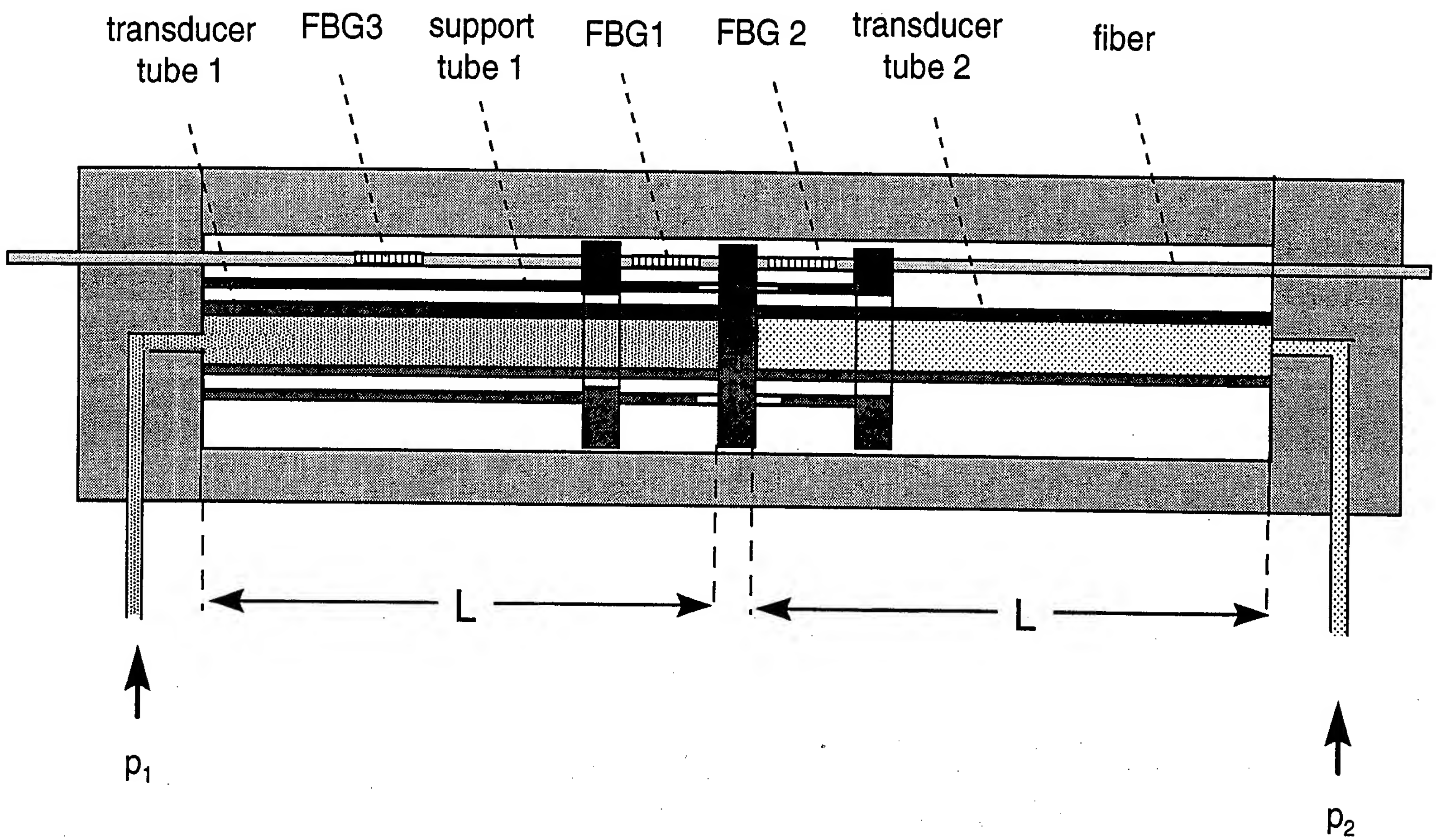
transducer tube 1
FBG3
support tube 1
FBG1
FBG 2
transducer tube 2
fiber
L
L
p_1
p_2

Figure 5

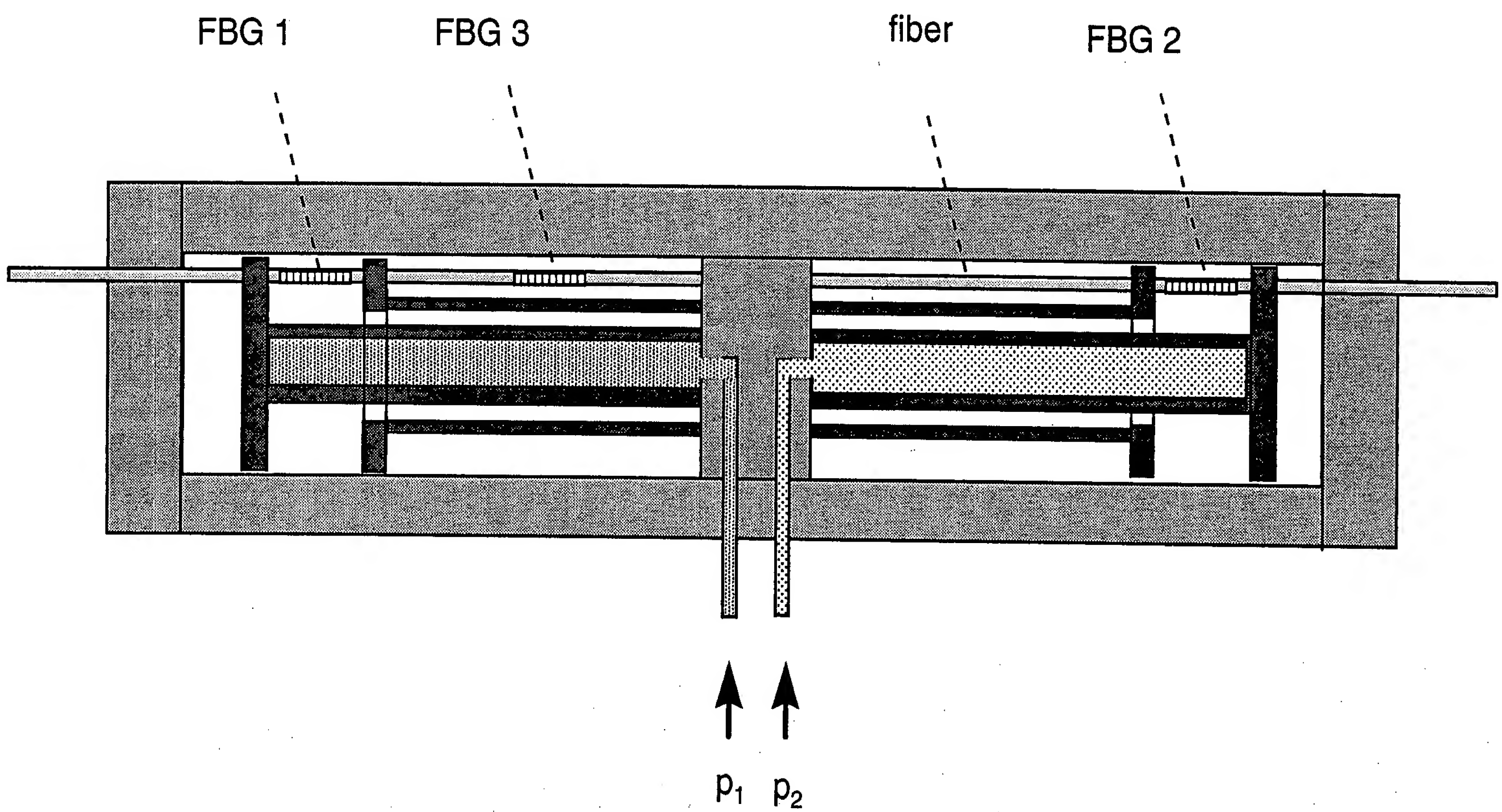

Figure 6

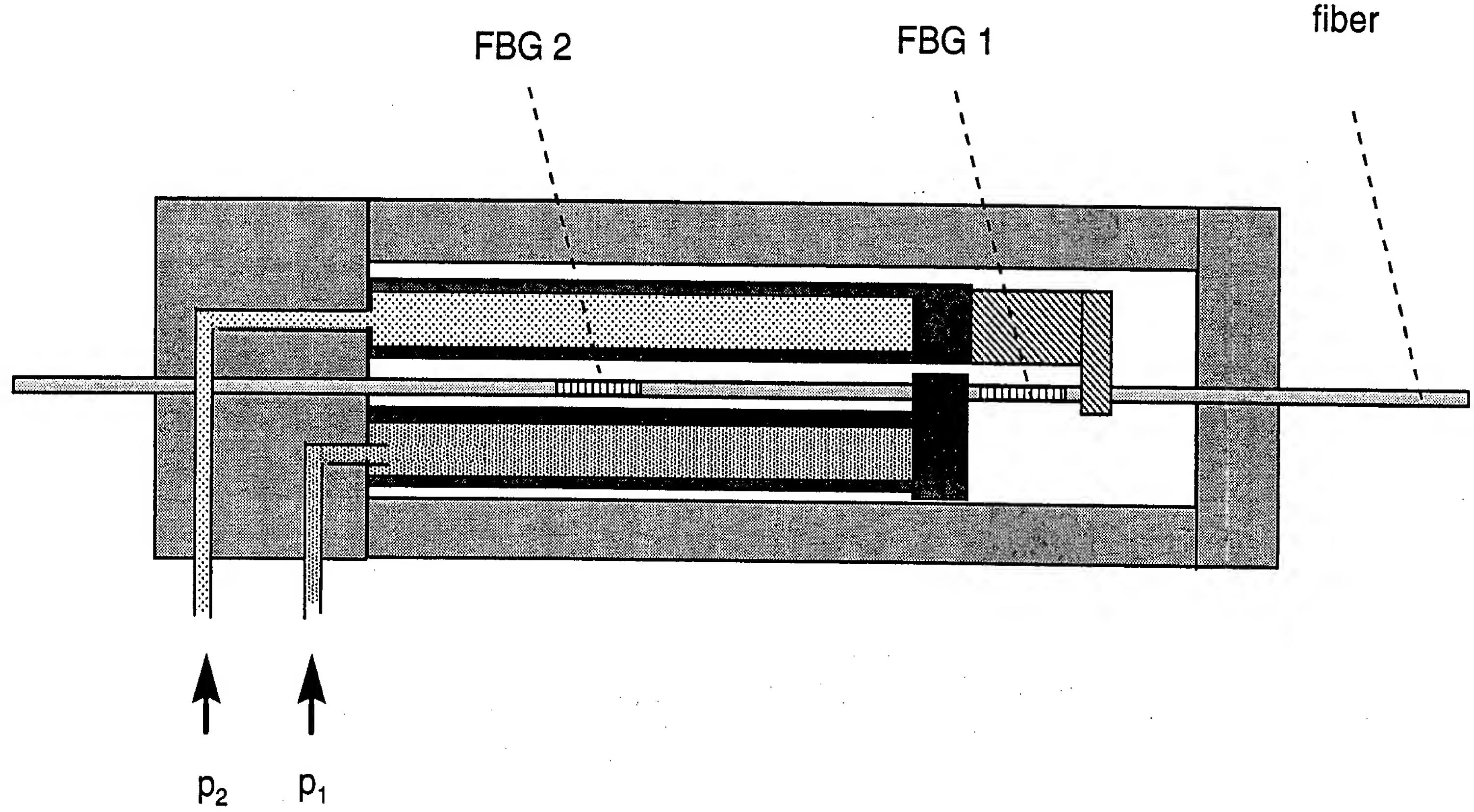

Figure 7

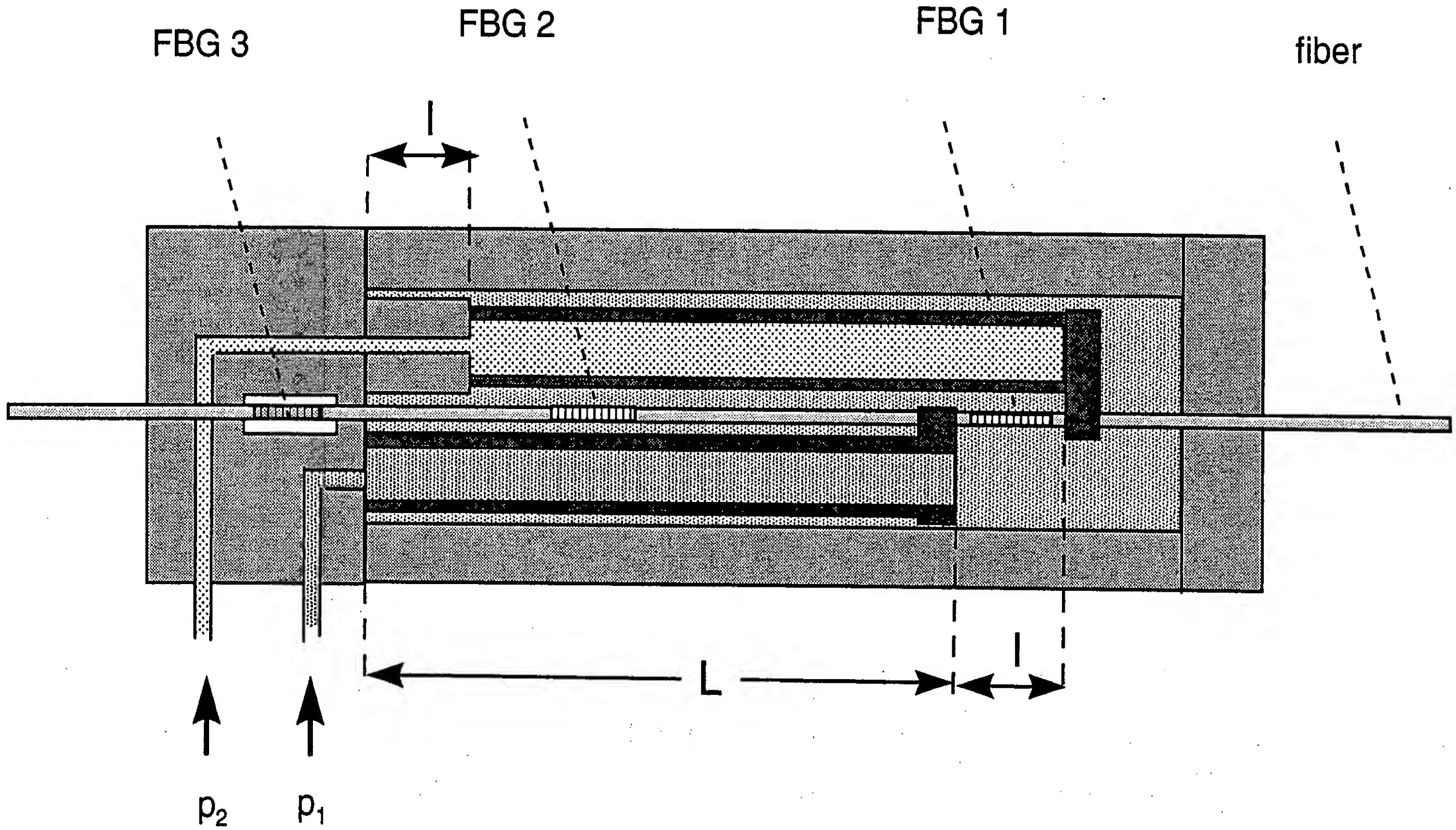

Figure 8

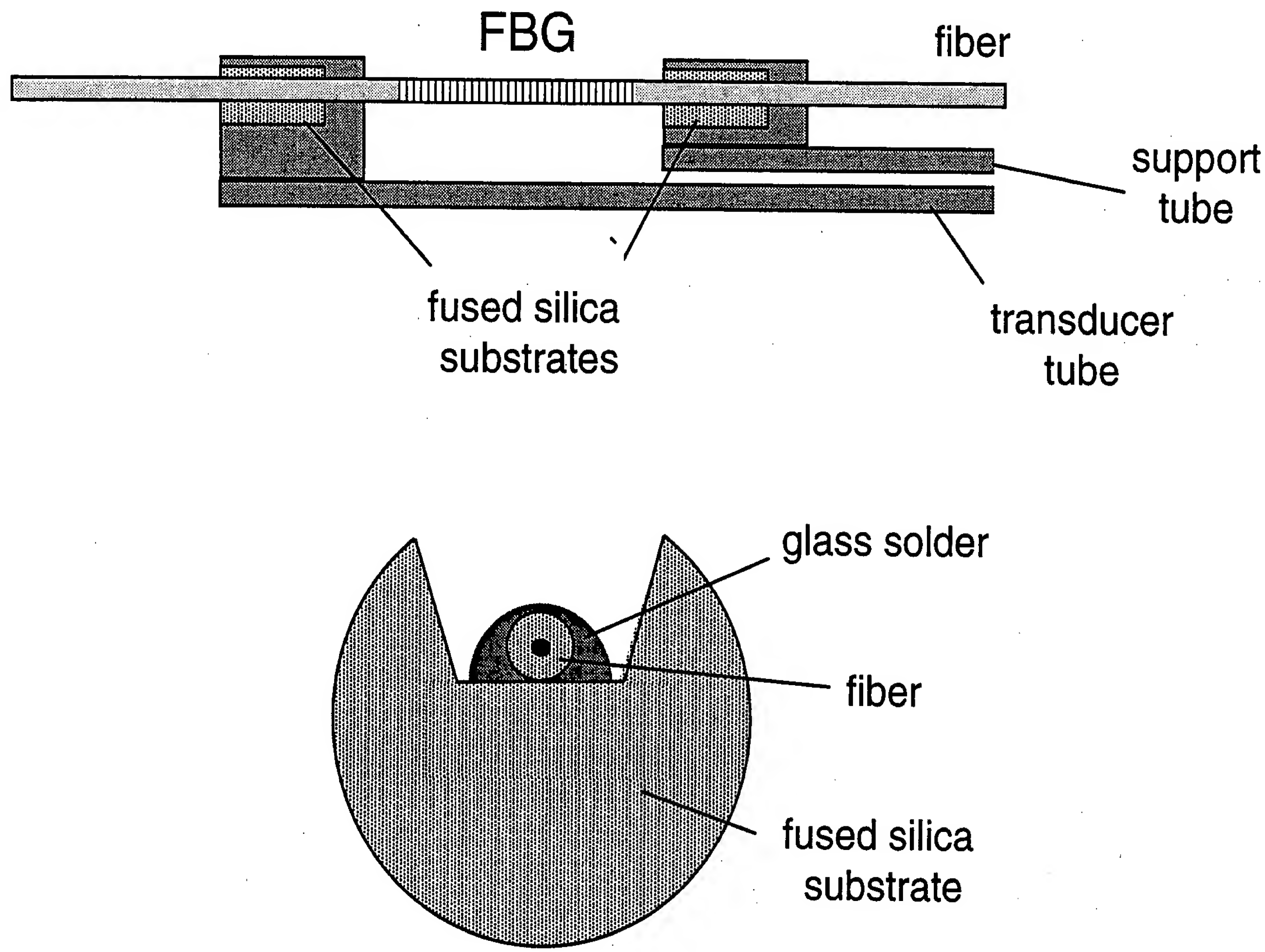
FBG
fiber
support tube
fused silica substrates
transducer tube
glass solder
fiber
fused silica substrate

Figure 9

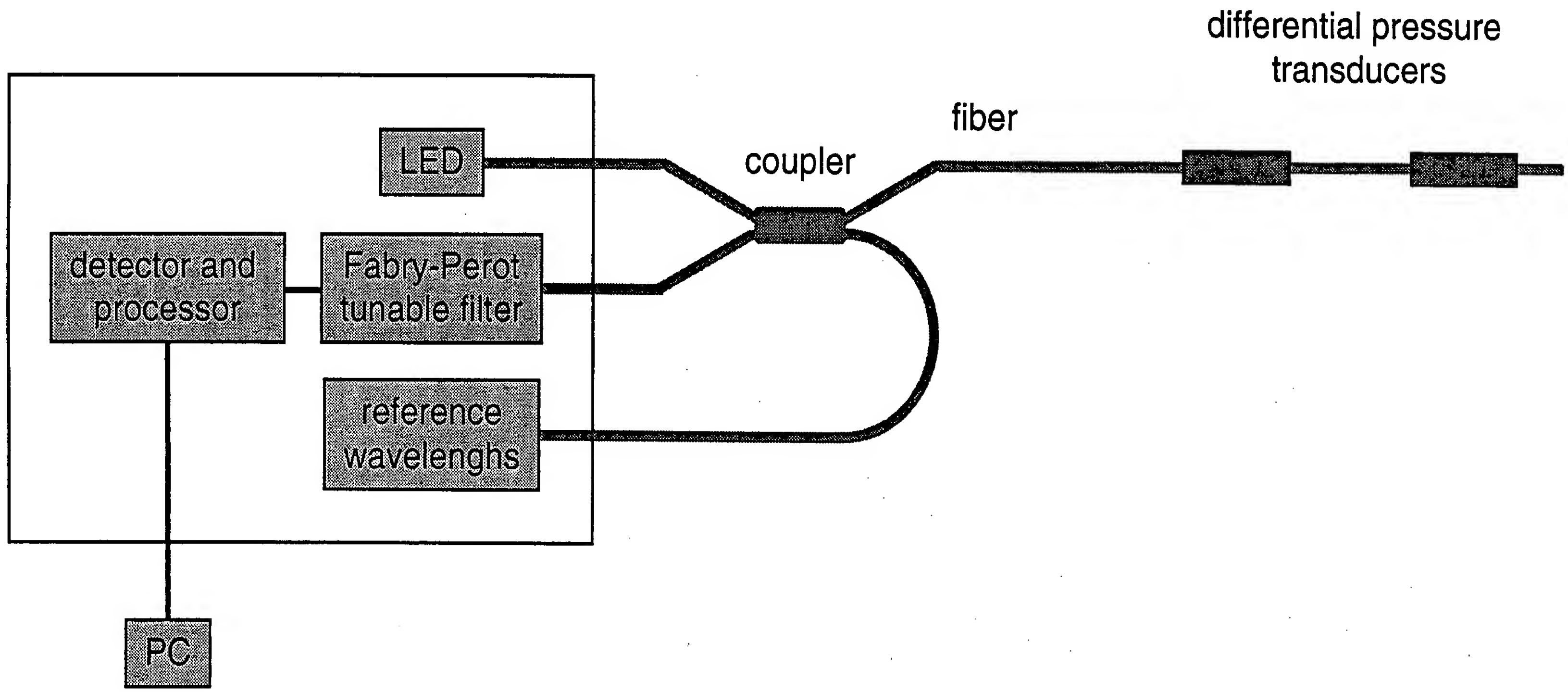
differential pressure transducers
fiber
coupler
LED
detector and processor
Fabry-Perot tunable filter
reference wavelenghs
PC

Figure 10

Venturi nozzle

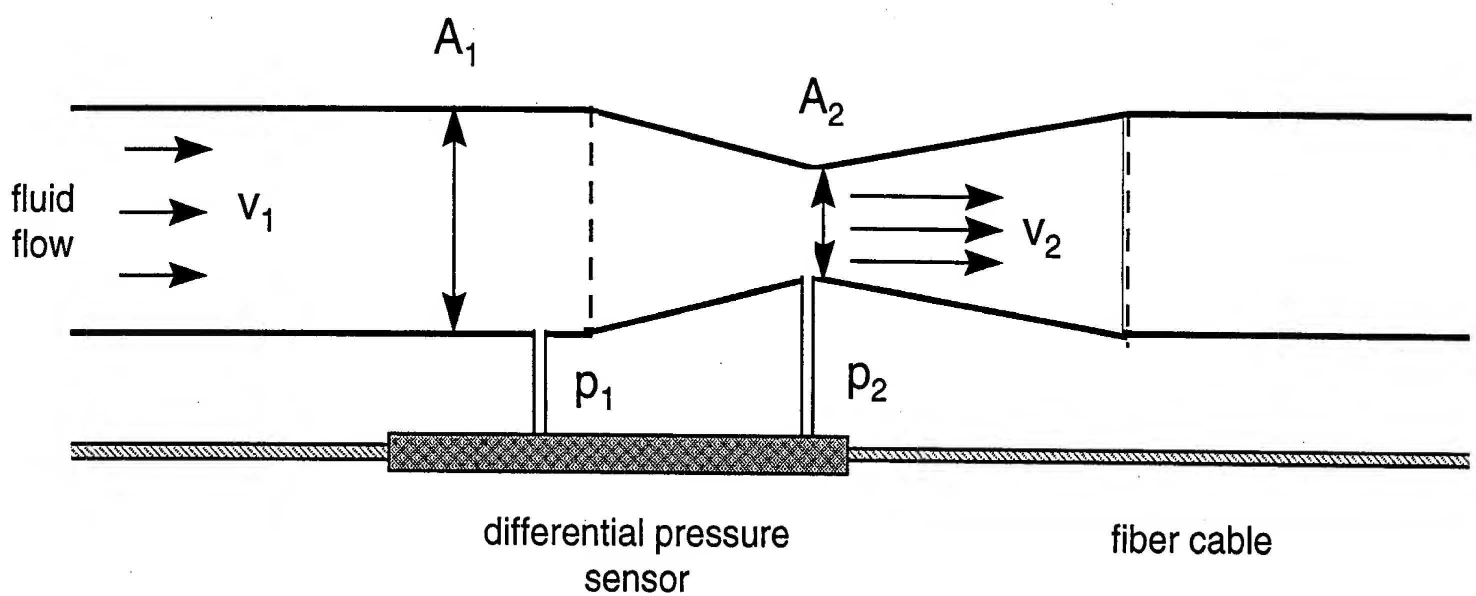

Figure 11

Exhibit 2

ABB

V-Nr.: 98207 Mp-Nr.: 98/277

Ort		Name	Von Abt. / Gruppe	Name	Tel. int.	Datum
	Gruppenleiter	Dr. H. Brändle	CHCRCE3	K. Bohnert	68044	[redacted]
	Abteilungsleiter	Dr. W. Rüegg				
	Direktor	Dr. O. Lanz				
Ba	TEI	~~Dr. Lück~~ B. Weibel				

Erfindungsmeldung

TEI Eingang [redacted] Frist SB Ert Abl

Erfinder

Name(n):	Tel.-Nr.:	Unterschrift:
Klaus Bohnert	68044	K. Bohnert
Hubert Brändle	67090	H. Brändle

Titel der Erfindung: Fiber Bragg grating sensor for differential pressure measurements

Beilagen: Beilagen folgen mit separater Post

Bemerkung: Falls möglich sollte Hr. Dr. Ingold die Patentanmeldung bearbeiten.

A. Stellungnahmen

1. Gruppen- / Abteilungsleiter

Betrifft Projekt: ARMS 9954 / E3-10-~~70~~

Nr.:

Vorlage beim nächsten PRB ☐

Dringliche Anmeldung (AD) ☒

Bemerkungen:

Datum: [redacted] Unterschrift GL: H. Brändle

Datum: Unterschrift AL: W. Rüegg

2. Direktion

PRB-Vorlage am ☐ [redacted]

Dringliche Anmeldung (AD) ☒

SB JM/141 R 3
Erstanm.
Z. Abt. CRCE3
Z. BA ZCR
Z. KGS CHCRC
Anm. CH RES
Vis./Dat. lia [redacted]

Bemerkungen:

Datum: [redacted] Unterschrift: M. Kogelschatz

ABB Corporate Research Ltd, Baden

Postal address: CH-5405 Baden-Dättwil, Switzerland Telephone: +41-56-486 84 11 Telefax: +41-56-493 55 61

Exhibit 3

ABB

-Dokumentenart/*Type of document*	Klassifizierung/*Classific.*	Ablageinformation (Reg.-Nr./Dateiname)/*Inform. for filing*
Interne Post		

Ort/*Pl.*	von Abt./*from Dept*	Verfasst von Hr./Fr./Frl./*from Mr./Mrs./Miss*	Tel. int./*Phone*	Datum/*Date*	TotSeit/*Pages*
Ba	TEI	Gertraud Müllauer	55265	[redacted]	1

Betreff/*concern:*

Ihre Erfindungsmeldung vom [redacted]

Titel: Fiber Bragg grating sensor for differential pressuer measurements

	an Abt./*to Dept*	an Hr./Fr./Frl./*to Mr./Mrs./Miss*	Anz.	Bemerkungen/*Notes*
Dä	CRCE3	Bohnert K.		
Dä	CRCE3	Brändle		

Wir haben Ihre Erfindungsmeldung mit bestem Dank am [redacted] erhalten und unter der V-Nr. 98207 registriert.

Wir bitten Sie, keine Informationen an Dritte, keine Offerten ohne Vorbehalte, keine Veröffentlichungen (Prospekte, Zeitschriftenartikel, Ausstellungen, usw.) vorzunehmen , bevor unsere Bestätigung der erfolgten Anmeldung vorliegt, da sonst Ihre Erfindung neuheitsschädlich getroffen werden könnte.

Die Anmeldung wird von Herrn Dr.J. Meier Telefon: 52659 bearbeitet.

Ihre Erfindungsmeldung wird an der PRB-Sitzung vom [redacted] besprochen. Über das weitere Vorgehen werden Sie danach wieder informiert.

Mit freundlichen Grüssen

TEI Immaterialgüterrecht

G. Müllauer

Beilage: Kopie Titelblatt der Erfindungsmeldung

Visum/*Signature*

ABB

Exhibit 4

Einschreiben

E. Blum & Co
Patentanwälte VSP
z. Hd. Dr. M. Ingold
Vorderberg 11

8044 Zürich

Bearbeiter
Dr. J. Meier
Abteilung
Immaterialgüterrecht (TEI)
Telefon (direkt)
+41/56/205 26 59
Telefax (direkt)
+41/56/205 76 55

E-Mail
juerg.meier@chabb.mail.abb.com

Ihr Zeichen	Ihre Nachricht vom	Unser Zeichen (bitte wiederholen)	Datum
		Siehe unten	

Sehr geehrte Herren

Besten Dank für Ihre Bereitschaft, für ABB einige weitere Patentanmeldungen auszuarbeiten.

Wir bitten Sie, für folgende Erfindungsmeldungen einreichefertige Unterlagen für Patentanmeldungen sowie einen Abstract in Englisch zu erstellen.

V 98114 (Byatt)
V 98207 (Bohnert)
V 98189 (Bohnert)
V 98186 (Dzung)
V 98166 (Draber)
V 98222 (Sabbattini)

Die Anmeldung von A. Byatt hat höchste, diejenigen von K. Bohnert haben hohe Priorität.
Der Erfinder D. Dzung wird Sie persönlich kontaktieren, um eine Reihenfolge der Bearbeitung seiner Erfindungsmeldungen festzulegen.
Zur Erfindungsmeldung von Frau S. Draber sind auf der beiliegenden Diskette der Text sowie weitere Graphiken vorhanden.

Wir freuen uns auf eine weiterhin gute Zusammenarbeit und verbleiben
Mit freundlichen Grüssen

Asea Brown Boveri AG

(J. Meier)

Anlage: 6 Erfindungsmeldungen
1 Diskette

E. BLUM & CO
PATENTANWÄLTE VSP
VORDERBERG 11, 8044 ZÜRICH
TELEFON: 01-261 54 54, TELEX 816 559
TELEFAX: 01-251 67 17

EINSCHREIBEN
Asea Brown Boveri Ltd.
z.Hd. Herrn Dr. Jürg Meier
Intellectual Property (TEI)
5401 **Baden**

TEI Eingang [redacted] Frist
En Abl

Zürich, [redacted]
Patente Dr.SU/Dr.MI/m
Unsere Akte : R-98/01583
Ihre Ref : V-Nr.98207

Entwurf Patentanmeldung V-Nr.98207
Faser-Bragg-Gitter Sensor für differentielle Druckmessung

Sehr geehrter Herr Dr. Meier,

Anbei zur kritischen Durchsicht den Entwurf der Patentanmeldung V-Nr.98207, Differenzdruck-Sensor mit Faser-Bragg-Gitter.

Die Anmeldung wurde neuheitsmässig gegen die frühere 98/019 abgegrenzt und muss vor deren Veröffentlichung eingereicht werden.

Mit freundlichen Grüssen
E. BLUM & CO.
i.V. i.A.

Dr. K. Sutter Dr. M. Ingold

Beilage : Entwurf Patentanmeldung samt Zeichnungen

E. BLUM & CO
PATENTANWÄLTE VSP
VORDERBERG 11, 8044 ZÜRICH
TELEFON: 01-261 54 54, TELEX 816 559
TELEFAX: 01-251 67 17

Exhibit 6

Asea Brown Boveri Ltd.
zHv Herrn Dr. Jürg Meier
Intellectual Property (TEI)
Haselstrasse 16/699
5401 **Baden**

TEI Eingang	Frist
[redacted]	Visa
	SB
Er	Abl

Zürich, [redacted]
Patente Dr. MI/dp
Unsere Akte: R-98/1583
Ihr Zeichen: V-Nr. 98 207

Neue Patentanmeldung: "Faser-Bragg-Gitter Sensor für Differentielle Druckmessung"

Sehr geehrter Herr Dr. Meier

Anbei senden wir Ihnen die einreichefertige Anmeldung V-Nr. 98207, zusammen mit dem vom Erfinder korrigierten Einsichtsexemplar und der Übersetzung der Zusammenfassung. Die Texte und Bilder befinden sich auf der Diskette.

Mit freundlichen Grüssen
E. BLUM & CO.

i.V.	i.A.
Dr. R. Sutter	Dr. M. Ingold

Beilagen
Anmeldung
korrigiertes Einsichtsexemplar
Diskette